PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Sterilization of Surfaces by Gaseous Plasmas and Apparatus therefor

We, ARTHUR D. LITTLE, INC., a corporation organised under the laws of the Commonwealth of Massachusetts, United States of America, of 25 Acorn Park, Cambridge, Massachusetts, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

This invention relates to the treatment of surfaces and to apparatus therefore, and more particularly to the treatment of surfaces of materials which are not amenable to induction heating, such as glass, plastics and ceramics to render them sterile, i.e., free from microorganisms.

A wide variety of pharmaceuticals, foodstuffs, and beverages are dispensed in glass or plastic containers, and in many cases it is necessary that the surfaces of these containers which are to come in contact with the material contained be sterile or free from any microorganisms such as bacteria and the like. Heating such containers to a temperature which is sufficient to destroy the microorganisms is the general technique used in sterilizing. In the case of glass containers it is desirable, for the sake of economy, to use the cheapest grades of glass having thermodynamic properties and coefficients of thermal expansion which do not permit rapid heating and cooling. This in turn means that in order to sterilize ordinary glass containers, or even those formed of some of the more expensive grades, it is necessary to slowly heat and then slowly cool them to effect the sterilization. Since it is impractical in a large-scale filling operation to handle each container in this manner individually, it is customary to sterilize a large quantity of containers at one time. This in turn requires that the glass containers then be stored under completely sterile conditions until they can be filled.

Many plastic materials do not have melting points which permit intensive heat sterilization, and those that do require heating over a period of time and then subsequent cooling. Although the problem of the coefficient of thermal expansion in plastics may not be so marked as in the case of glass, cooling must still be accomplished and the plastic containers must be maintained under sterile conditions until filled. Similar problems arise in the case of ceramic articles.

Although some filling processes will permit hot filling many will not, thus necessitating having cool containers for filling. For example, many pharmaceuticals cannot be heated for filling and many foodstuffs would be overcooked if it were necessary to keep them hot for filling.

Inasmuch as materials such as glass, plastics and ceramics are not electrically conducting they do not lend themselves to induction heating, and dielectric heating is impractical for a surface treatment. It would therefore be desirable to have available a method for sterilizing glass, plastic, and ceramic surfaces which would not require storing and handling under sterile conditions until filled. Preferably such a method of sterilizing should be an additional step in the container filling procedure and integrated and timed with it.

Sterilization is achieved by contacting with the surface to be sterilized a plasma as hereinafter defined for a very brief period of time, normally not longer than one-tenth of a second. It is not completely understood by what mechanism this exposure destroys the microorganisms without apparently affecting the surface of the glass or plastic. The temperature of

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the plasma does not lend itself to accurate measurements, but it is known that it is far higher than that which would rapidly melt the glass or decompose the plastic if the surface were exposed to the temperature for any lengthier period of time. It therefore appears that under the conditions described the plasma attacks only the skin of the surface and that within the time period little if any heat is transferred to the body of the glass or plastic. This conclusion is borne out by the fact that containers thus sterilized inside are cool to the touch and can be readily handled immediately after treatment. Thus it appears that there is little if any heat transferred to or across the glass wall.

In order to achieve plasma sterilization, it is necessary to contact the surface only momentarily and this in turn requires that the plasma be generated and reach its full intensity within a very short but finite time, e.g. of the order of a few milliseconds. It is also of course necessary to be able to turn off the plasma once the sterilization has been accomplished and to sweep away any of the hot gas from the surface being treated in order that no undue heat is transferred to it. Thus, what is required is a "pulsed" plasma. In the following description the term "plasma" is used to define a highly or substantially completely ionized body of gas composed of positively charged nuclei and negatively charged electrons.

Induction plasmas are known and these may be generally defined as regions of highly ionized, high temperature gas maintained by inductively coupled high frequency electrical power. The inductive coupling of power into the gas is possible because the gas is ionized and is therefore conducting. Since gases are normally not ionized and not conducting, the production of an induction plasma involves a starting step in which sufficient initial ionizaton must be produced by some means. In most applications such initial ionization can be permitted to take place relatively slowly, and therefore starting techniques have generally employed a starting operation separate from generation and use of the main plasma body. For example, starting is often accomplished by first heating a carbon rod to such a temperature that it produces sufficient thermal ionization of the gas to initiate plasma formation which involves complete ionization of the gas to form positively charged nuclei and negatively charged electrons. It obviously requires a certain finite time to heat the carbon rod to start the plasma and hence a relatively large measurable period of time elapses before the main plasma is formed and maximum temperature is reached.

The present invention consists in a method of sterilizing the surface of a material which does not conduct electricity, wherein said surface is contacted with a gaseous plasma comprising an ionized body of gas for a period of time which is less than that required to effect any appreciable physical change, such as softening or charring, in said surface.

The present invention also consists in a method of sterilizing the interior of a container formed of a material which does not conduct electricity, comprising the steps of introducing an ionizable gas into said container; and rapidly ionizing said gas thereby forming a plasma within said container, the duration of the existence of said plasma being less than that required to effect any appreciable physical change, such as softening or charring, in the surface of said container.

The invention further consists in apparatus for sterilizing the surface of a material which does not conduct electricity, comprising in combination means for introducing an ionizable gas in contact with said surface; and means for generating a corona discharge within said gas thereby to ionize said gas and form a plasma which contacts said surface.

The invention also consists in apparatus for sterilizing the interior of a container formed of glass, plastic or ceramic, comprising in combination means for introducing an ionizable gas into said container and imparting to said gas a flow pattern which causes said gas to contact the wall forming said interior and sweep out of said container; means for generating a corona discharge within said gas thereby to ionize said gas and form a plasma within said container whereby said wall is rendered free from microorganisms.

In order that the invention may be more readily understood, reference will now be made to the accompanying drawings, in which:—

Fig. 1 illustrates a test set-up used to evaluate the method and apparatus in sterilizing glass slides;

Figs. 2—4 illustrate various modifications of the apparatus;

Fig. 5 illustrates a modification of the apparatus in which two different gases are supplied for ionization to form a plasma; and

Fig. 6 illustrates in somewhat simplified form a container filling assembly line showing the apparatus of this invention as an integral part thereof;

Figs. 7—9 illustrate circuits for generating plasma in accordance with this invention when the power supply is a high-voltage source;

Figs. 10—12 illustrate circuits in which the power supply is a medium-voltage source;

Fig. 13 illustrates a circuit in which the power supply is a low-voltage source;

Fig. 14 illustrates a modification of the basic circuit of Fig. 8; and

Fig. 15 shows the plasma generating equipment within an enclosure to provide an experimental environment.

Fig. 1 illustrates a test set-up used to evaluate the efficiency of plasma sterilization. This figure also illustrates an apparatus modi-

fication suitable for sterilizing solid bodies, such as slides, or the exterior of an article.

In assessing the efficiency of this method and apparatus as a means for sterilizing surfaces, glass microscope slides were introduced with different concentrations of bacteria on the slide, and it was found that concentrations up to 4×10^6 spores per square inch were totally destroyed in less than 1/10 of a second. In the apparatus of Fig. 1 a glass slide 10, held by means of a clamp 11, is positioned through a support 12 within a glass envelope 15, the bottom of which is open to the atmosphere. The envelope terminates in a neck 17 which has a gas inlet conduit 16 leading into it. Around envelope 15 is a coil 18, one end of which is electrically connected to ground 20, and the other to a suitable high voltage power supply 19, through suitable switching means 21. The switching means is only diagrammatically represented; it is described in detail below. An electrode 22 passes down through the neck 17 of the glass envelope into the interior of the envelope. The electrode is connected to ground 23 and within the envelope it terminates in a point 24 (drawn as an arrow to better illustrate it) which is located at a position corresponding to the high voltage end of the coil 18. By pulsing a voltage of approximately 7,000 volts into coil 18 there is established between point 24 and coil 18 a corona discharge which very rapidly generates a plasma 26 of the gas, e.g., argon, introduced through the gas inlet conduit 16 into envelope 15. The plasma can be generated and turned off at will merely by turning the power supply on and off.

In the establishment of a corona discharge it is of course necessary to provide a sufficient voltage gradient between the electrode point 24 and the coil 18 to ionize the gas used to form the plasma. The use of a corona discharge to form an induction plasma in effect achieves a "self-starting" plasma and employs the same means to provide initial ionization as well as to sustain it. Various circuits capable of generating the corona discharge to produce a pulsed plasma are described below.

Figs. 2—4 illustrate the application of plasma sterilization to various types of glass or plastic containers, and in these figures like numbers refer to like elements described in Fig. 1. In Fig. 2 bottle 29 is sterilized in accordance with the practice of this invention by supplying within the container a flow of ionizable gas suitable for forming a body of plasma. This is conveniently done with a suitable gas supplying reservoir 30 equipped with a gas inlet conduit 31 and means for directing the flow of gas into the container such as neck 32 which in this case is inserted into the bottle 29. If desired, the gas may be directed tangentially into reservoir 30, thus giving it a swirling motion which is at least partially retained within the bottle 29. In the arrangement in Fig. 2 the corona discharge responsible for generating the plasma is located at the top of the bottle and the flow of gas insures the distribution of the plasma over the entire inner surface of the bottle 29.

In Fig. 3 the neck 32 of the gas introducing means extends almost to the bottom of the wide-mouthed bottle 34 which is to be sterilized. Likewise the electrode 22 extends through this neck and the electrode point 24 is located near the bottom of the bottle. This of course means then that the high power side of the coil 18 must be at the bottom rather than at the top as in Fig. 1 or 2. The plasma-forming gas flows down through neck 32 and sweeps the plasma formed at the corona discharge up through the bottle and out through its opening.

Fig. 4 illustrates an apparatus modification which permits the sterilization of the outside as well as the inside of a bottle 34. In this modification the means for providing an ionizable gas comprises a conduit 37 which extends almost to the bottom of the inside of the jar 34 and an outer envelope 38 which defines a plasma containing volume 35 around the jar 34. By introducing an ionizable gas, e.g., argon, into conduit 37 and providing sufficient power to coil 18, the corona initiates a plasma within the jar 34 and the plasma then spreads to fill the envelope 38 thus sterilizing both the internal and external walls of container 34.

Fig. 5 illustrates an apparatus designed to use two different ionizable gases to form the plasma. For example it may be desirable to use a nitrogen plasma. However, it is much more difficult, particularly as far as power requirements are concerned, to generate a nitrogen plasma due to its diatomic nature than it is an argon plasma, for example. The use of an argon plasma as a pilot to initiate the formation of the nitrogen plasma makes the use of a nitrogen plasma much more feasible. In the apparatus of Fig. 5 a bottle 40 is sterilized by inserting into it a tube 41 which has a gas inlet line 42 suitable for introducing nitrogen, for example, into the bottle. The electrode in this case is a small-diameter tungsten tube 43 which is capable of introducing argon into the bottle. This tungsten tube 43 is grounded at 44 and terminates within the bottle at a sharp point 45 thus providing the necessary configuration for the establishment of a corona discharge between it and the coil 18. Once this corona discharge is created, nitrogen flowing in the annular space defined by tube 41 and tungsten tube 43 is ionized, a plasma is formed of the nitrogen, and the interior wall of the bottle is sterilized.

Fig. 6 illustrates, in simplified form, how the plasma sterilization method and apparatus of this invention may be incorporated into an automated bottle filling operation. Bottles 48

which are to be filled are placed on a suitable moving means such as an endless belt 49 which is periodically advanced by rolls 50 by means not shown. At the sterilizing station there is provided means 53 for picking up and raising the bottle into position within the sterilizing equipment designated generally by numeral 52. As an alternative, means may be provided for moving the sterilizing equipment downwardly over the bottle. Once the bottle has been sterilized, it is returned to its position on belt 49 which advances the now sterile bottle to the filling station to be filled by suitable filling means 54. It is of course possible to use one steriliizng station for a number of filling lines and the sterilizing and filling operations can be timed and coordinated to meet any set of conditions.

In the formation of a plasma it is of course necessary to ionize the gas provided for plasma formation. Preferably such a gas is a monatomic gas such as argon, helium, xenon, and the like. Fig. 5 illustrated apparatus in which it is possible to use a readily ionizable gas to initiate plasma formation in another gas such as nitrogen. It is also of course possible to use diatomic gases such as nitrogen to form the plasma, provided however sufficient voltage drop is created between the coil and the electrode point. Although many gases may be used, argon is preferable since it is inert, non-toxic, and readily available. It may not be advisable to use air or oxygen in forming the plasma since by-product nitrous oxide or ozone, respectively, will be formed in using these gases and means must be provided to remove these undesirable gases prior to filling a container.

In the plasma generation apparatus of this invention an induction plasma is very rapidly formed when high-frequency electrical power is applied to a suitable gas. In doing this the high-frequency electrical power is supplied at a sufficiently high voltage to establish a corona discharge at one or more sharply pointed electrodes in the gas. This corona discharge provides the initial ionization required to produce the induction plasma; and since the initial corona discharge and plasma are produced by the same electrical power used to maintain the plasma, there results a self-starting induction plasma which rises to its maximum temperature extremely rapidly. Thus it will be apparent that by merely turning the high voltage on and off it is possible to pulse the plasma and to produce it at its maximum temperature at will and for any desired length of time. This makes it particularly suitable for use in sterilizing containers and the like as described.

The corona required to initiate and maintain the plasma may be produced at a high voltage electrode near ground or at the low voltage side of a high frequency coil. Conversely, a grounded electrode near the high voltage side of the coil may be used. Figs. 1 and 2 illustrate these embodiments and show circuits suitable for producing the necessary corona using a standard induction heating power supply.

In Fig. 7 the corona 110 is seen to be formed between the low-voltage side of a work coil 111 and the high-voltage electrode 112 which terminates in a point 113, illustrated for convenience as an arrow point. Work coil 111 has a ground 114 and is supplied with high-voltage, high-frequency power from a standard induction heating power supply 115. These induction heating supplies are well known and are described for example in Simpson, P.G. "Induction Heating" McGraw-Hill Book Co., Inc., 1960. It will be appreciated that in the circuit of Fig. 7 there is a large potential drop between electrode point 113 of electrode 112 and the grounded side of work coil 111. Typically in the circuit of Fig. 7 the voltage at the point where electrode 112 is connected to work coil 111 will be in the range of about 5,000 to 10,000 volts.

In Fig. 8 the corona 110 is formed between the electrode point 113 of the grounded electrode 112 (grounded at 116) and the high voltage side of work coil 111.

The frequency of the high voltage power may range from as low as 0.3 megacycles up to about 300 megacycles, with a preferred range being 5 to 10 megacycles. This range therefore encompasses what are generally referred to as the medium frequency, high frequency and very high frequency bands. Fig. 9 illustrates the use of a typical commercially available high frequency, high voltage supply source which may be used to supply power to the work coil 111. It has the advantage of being able to deliver a variable voltage, of being controlled at various points in the circuit, and of providing a choice of switching points. The power supply circuit comprises a series of controllable rectifiers 116 coupled to a three-phase power line. The flow of dc power entering this high voltage machine may, if desired, be controlled by switch 117. However, this is not the preferred point in the circuit to control the turning of the plasma on and off. The voltage available for initiating the plasma, which is the voltage across the tank circuit (comprising the capacitor 121 and coils 111 and 122) is adjustable to the desired level through control of the dc plate voltage of triode 118 by means of controllable rectifiers 116. Turning of the plasma on and off and the actual duration of the plasma can be controlled by a power contactor 119 in the three-phase power line, through the controllable rectifiers 116, through switch 117 in the high voltage dc line, or by a switch 123 in the cathode. As an alternative to using switch 123, control may be effected through the equivalent of switch 123 biasing the triode

118 to cutoff by means of an auxiliary bias supply 124 in the grid circuit.

Figs. 10—12 illustrate circuits suitable for generating plasma in accordance with this invention wherein the power sources can be considered to be medium voltage sources, i.e., in the range of 1000 to 5000 volts. In Figs. 10 and 11 voltages in the coils are increased to the necessary level by use of an autotransformer, i.e., a transformer in which part of the winding is common to both the primary and secondary circuits. In Fig. 10 the work coil 111 is in effect a combination of coils 129 and 130; while in Fig. 11 voltage at electrode point 113 is enhanced by the use of the secondary coil 134 coupled to work coil 111. Fig. 12 shows the use of a resonant circuit comprising a capacitor 137 is conjunction with the work coil 111 which in turn is connected to the high-voltage side of medium voltage sources 128 through an isolating coil 136.

Fig. 13 illustrates a circuit which permits the use of a low-voltage power source such as an induction heater with a stepdown output transformer. The low voltage supply circuit of Fig. 13 comprises a step-down output transformer 140 having a primary winding 139 and secondary winding 142, and this in turn is connected to a series resonant circuit including capacitor 143 which serves to increase the voltage across work coil 111.

Fig. 14 illustrates the use of a choke in connection with the basic circuit of Fig. 8. A similar choke can, of course, be incorporated in the other circuits of Figs. 7 and 9—13. With the generation of a plasma 110 there is established a high conductivity path between electrode point 113 and work coil 111. This gives rise to a large current flow that will heat up electrode point 113 and short out the work coil 111. By inserting a choke 147 into the circuit the current flow in this high-conductivity path is reduced and the coil is not shorted out. It may also be desirable to have available additional starting voltage and this is provided in the circuit of Fig. 14 by coupling from the work coil 111 to a coil 146 in the starting electrode circuit. This, it will be appreciated, is in effect an autotransformer similar to that shown in Fig. 10.

The above description of the method and apparatus of this invention has been presented in terms of forming a plasma by ionizing air. It may, of course, be desirable to form plasmas of other gases, particularly of monatomic gases such as argon, xenon, and helium for example. These monatomic inert gases are preferred because the power required to ionize them is much less than for a diatomic gas such as nitrogen or oxygen and the plasma does not contain any by-product harmful gases such as nitrous oxide or ozone. Thus, it is contemplated as within the scope of this invention to include means for providing a gas around this corona discharge or for providing enclosure means to contain at least that portion of the circuit wherein at least a part of the corona is formed and means for introducing or circulating gas within the enclosure. Such means for providing gas and enclosure means may of course take many forms, depending upon the use for the plasma formed. In the case of container sterilization the container itself will conveniently form the enclosure and any suitable conduit means for circulating a gas within the container may be used. The use of an enclosure is, of course, predicted on the ability of the material from which it is formed to withstand the temperatures of periodic pulses of plasma. Since the apparatus of this invention is designed primarily to furnish plasmas of short duration, the use of such an enclosure, for example to house a test specimen, is feasible.

Fig. 15 illustrates apparatus embodying means for using a gas other than air and for supplying a contained plasma. The work coil 111 and electrode point 113 are located within a housing or enclosure 150 which defines a plasma volume 151. The placing of the work coil within the enclosure is possible if the coil is in some manner physically isolated from the plasma-forming gas. If the coil is to be located within the enclosure then it must be so isolated such as by being wrapped or encased with an electrically nonconducting material. An alternative way is to place the coil around the outside of the enclosure and use the enclosure walls as the means of physically isolating the work coil from the plasma-forming gas. In the apparatus of Fig. 15 conduit means 152 and 153 are provided for introducing and withdrawing a plasma-forming gas. Support means 154 hold a test specimen 155 in position within the plasma volume.

The actual voltage required to form the plasma will depend upon a number of factors, including the sharpness of the discharge point or points, the frequency of the current supplied, the gas used in forming the plasma and whether or not the plasma is enclosed within a specified volume. It is therefore not possible to indicate a specific voltage range since it will vary from system to system and optimum voltage levels may be readily determined for any one system. In general, the sharper the discharge point, the less voltage is required; and the lower the frequency used, the larger will be the minimum size of the plasma which can be formed. The gas used to form the plasma has a great influence upon the power required. For example, to generate a plasma in nitrogen requires from two to five times the voltage required to generate a plasma in argon under otherwise the same operating conditions. Typically, root mean square (RMS) voltages of about 5000 volts will be required for forming an argon plasma, with peak voltages being about 7000 volts.

It is to be understood that the circuits shown in Figs. 7—14 are to be considered only illustrative of the many types of circuits which can be used to provide the power required for the formation of the necessary corona discharge in the plasma-forming gas. Many other circuits and modifications of circuits will be available to those skilled in the art and it is meant to include any circuit suitable for providing the high frequency high voltage power.

The method and apparatus of this invention is particularly well suited for supplying pulsed plasmas in applications where it is required to have a source of intense heat which requires only a very short time to reach maximum intensity. By furnishing a "self-starting" plasma it is possible to provide such a heat source for any desired length of time.

The manner in which the ionizable gas is supplied to the container or around the body to be sterilized may be any way which is suitable for providing a quantity of the gas to the volume in which the plasma is formed. The figures illustrate typical introducing means and the gas may be delivered to these either as a single mass prior to plasma formation or it may be continuously circulated during the existence of the plasma.

From the description of the apparatus of Figs. 1 through 5 it will be seen that the equipment is operated at atmospheric conditions which is, of course, advantageous both with respect to ease of operation and economy. If pressurized gas is used, then the voltages required to form the plasma will be greater and although it is possible to use pressurized gases, no real advantage will be realized.

It will be appreciated from a general knowledge of plasmas that the time period over which the surface is actually exposed to these extremely high temperatures must be relatively short. Exposure times depend upon the material being treated and the plasma being used; and they should, of course, be of sufficient duration to destroy the microorganisms on the surface but less than that which will effect any appreciable physical change in the surface, i.e., less than that which will melt the glass, degrade the plastic or fuse the ceramic surfaces. In general, it is preferred that exposure times should be no longer than about one-tenth of a second for glass and somewhat less than that for plastic surfaces. It is apparently sufficient to treat only the skin of the glass or plastic wall.

Plasma sterilization has a number of advantages which have been pointed out and which may be summarized as including high efficiency, ability to sterilize individual pieces just prior to filling, no requirement of cooling and ability to be integrated directly into a filling assembly.

WHAT WE CLAIM IS:—

1. Method of sterilizing the surface of a material which does not conduct electricity, wherein said surface is contacted with a gaseous plasma comprising an ionized body of gas for a period of time which is less than that required to effect any appreciable physical change, such as softening or charring in said surface.

2. Method as claimed in claim 1, wherein said gaseous plasma is formed of argon.

3. Method as claimed in claim 1 or 2, wherein said material is glass.

4. Method as claimed in claim 1 or 2, wherein said material is a plastic.

5. Method as claimed in any one of the preceding claims, wherein said period of time does not exceed one-tenth of a second.

6. Method of sterilizing the interior of a container formed of a material which does not conduct electricity, comprising the steps of
(a) introducing an ionizable gas into said container; and
(b) rapidly ionizing said gas thereby forming a plasma within said container, the duration of the existence of said plasma being less than that required to effect any appreciable physical change, such as softening or charring, in the surface of said container.

7. Method as claimed in claim 6 wherein said ionizing is accomplished by creating a corona discharge within said gas.

8. Method as claimed in claim 6 or 7 wherein said container is glass.

9. Method as claimed in claim 6 or 7, wherein said container is plastic.

10. Method as claimed in any one of claims 6 to 9, wherein said gas is argon.

11. Method as claimed in any one of claims 6 to 9, comprising the steps of
(a) introducing into said container a first readily ionizable gas;
(b) rapidly ionizing said first readily ionizable gas thereby to form an initial plasma; and
(c) introducing a second less readily ionizable gas within said container to form a primary plasma body the formation of which is initiated by said initial plasma; the total duration of said initial plasma and said primary plasma being less than that required to effect any appreciable physical change such as softening or charring, in the surface of said container.

12. Method as claimed in claim 11 wherein said readily ionizable gas is argon and said less readily ionizable gas is nitrogen.

13. Apparatus for sterilizing the surface of a material which does not conduct electricity, comprising in combination
(a) means for introducing an ionizable gas in contact with said surface; and
(b) means for generating a corona discharge within said gas thereby to ionize said

gas and form a plasma which contacts said surface.

14. Apparatus for sterilizing the interior of a container formed of glass, plastic or ceramic, comprising in combination

(a) means for introducing an ionizable gas into said container and imparting to said gas a flow pattern which causes said gas to contact the wall forming said interior and sweep out of said container;

(b) means for generating a corona discharge within said gas thereby to ionize said gas and form a plasma within said container whereby said wall is rendered free from microorganisms.

15. Apparatus as claimed in claim 13 or 14 including means for generating a plasma, comprising in combination

(a) a work coil;

(b) an electrode terminating in at least one electrode point, said electrode point being located in close proximity to said coil; and

(c) high-frequency power supply means electrically connected to said coil and adapted to deliver high voltage power thereby to establish between said coil and said electrode point a corona discharge of sufficient intensity to ionize gas surrounding said corona to generate a plasma.

16. Apparatus as claimed in claim 15, wherein said high-frequency power supply means is an induction heating power supply.

17. Apparatus as claimed in claim 15, wherein said high-frequency power is a medium voltage source and a series resonant circuit.

18. Apparatus as claimed in claim 15, wherein said high-frequency power supply means is a medium voltage source and an autotransformer.

19. Apparatus as claimed in claim 15, wherein said high-frequency power supply means is a low voltage source and a series resonant circuit.

20. Apparatus as claimed in any one of claims 15 to 19, wherein choke means is associated with said electrode and adapted to limit current flow in said electrode.

21. Apparatus as claimed in claim 20 including a coil associated with said electrode and adapted to be coupled with said work coil in starting said apparatus.

22. Apparatus as claimed in any one of claims 15 to 21, wherein enclosure means surround at least that portion of the electrical apparatus in which said corona discharge is formed; and means is provided for supplying an ionizable gas to said enclosure.

23. A method of sterilizing the surface of a material substantially as hereinbefore described.

24. Apparatus for sterilizing the surface of a material substantially as hereinbefore described with reference to Figure 1, 2, 3, 4, 5 or 15 of the accompanying drawings.

25. A container filling assembly line including apparatus as claimed in any one of claims 13 to 22 or 24.

26. Apparatus for sterilizing the surface of a material substantially as hereinbefore described with reference to Figure 1, 2, 3, 4, 5 or 15 of the accompanying drawings including a plasma generation circuit substantially as hereinbefore described with reference to any one of Figures 7 to 14.

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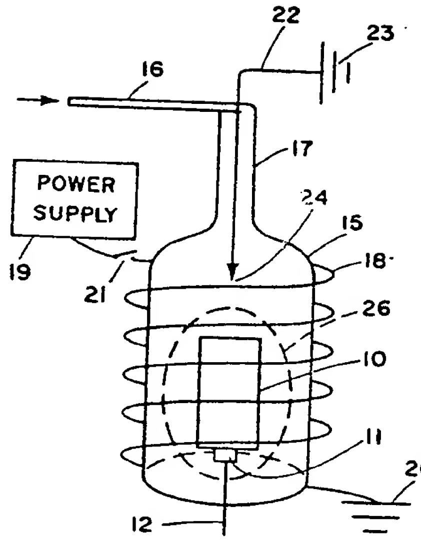

Fig. 1

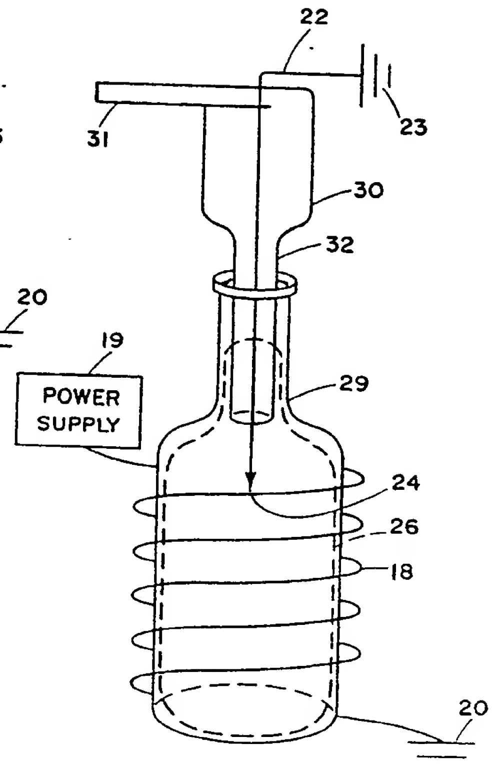

Fig. 2

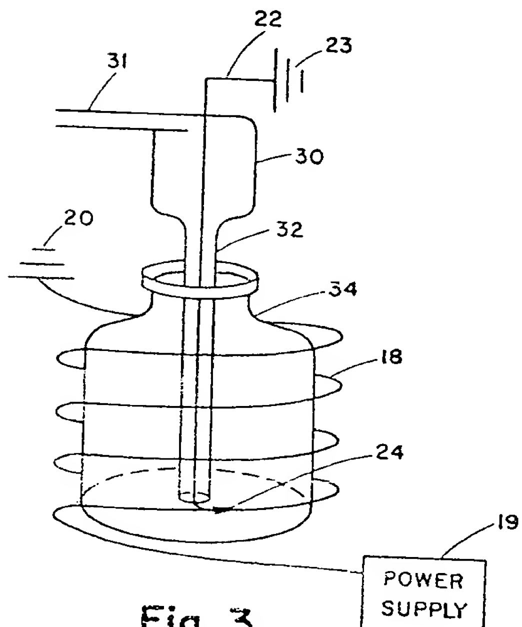

Fig. 3

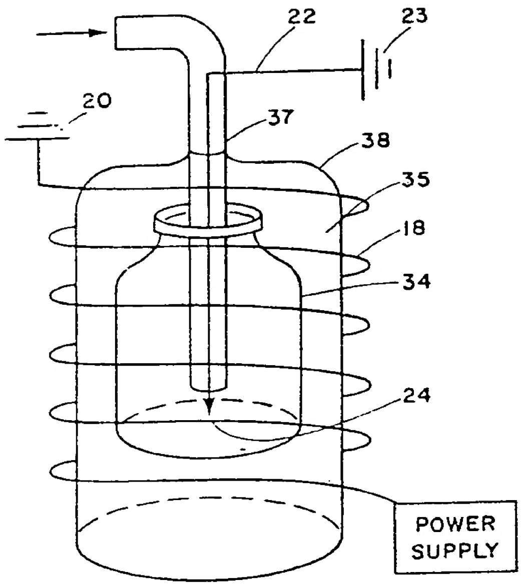

Fig. 4

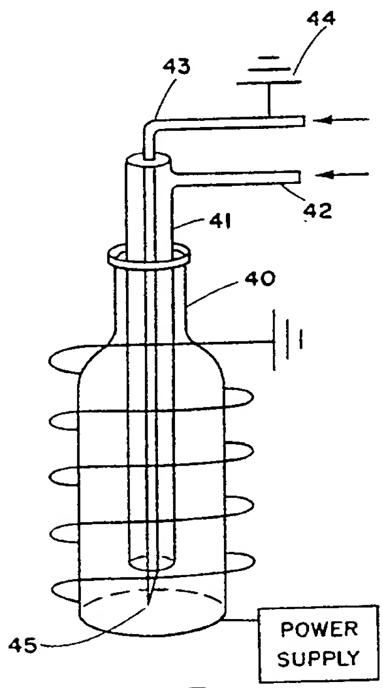

Fig. 5

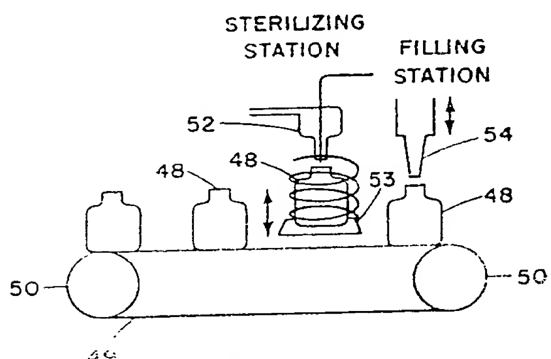

Fig. 6

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4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 1 & 2

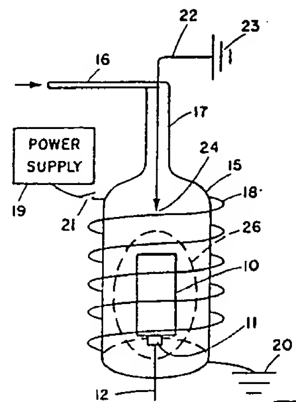

Fig. 1

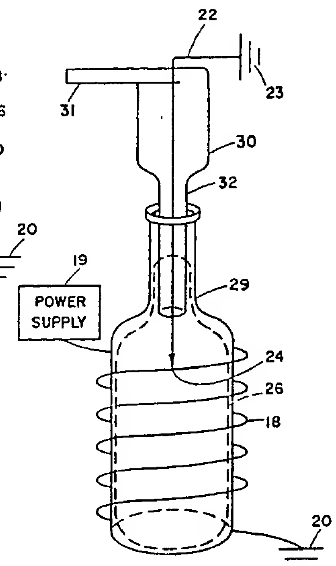

Fig. 2

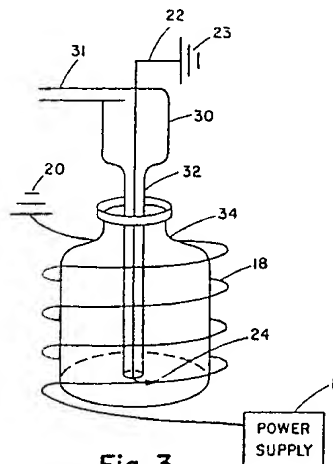

Fig. 3

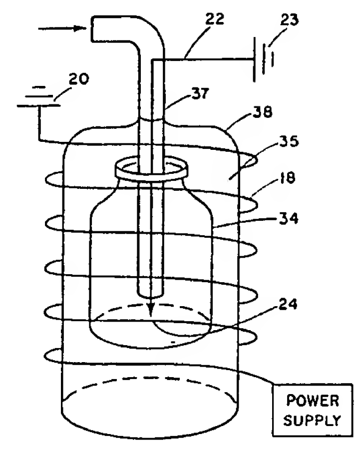

Fig. 4

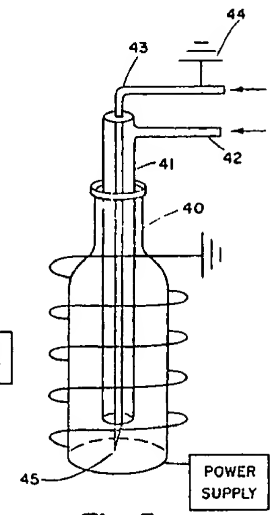

Fig. 5

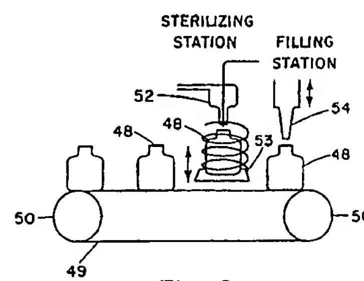

Fig. 6

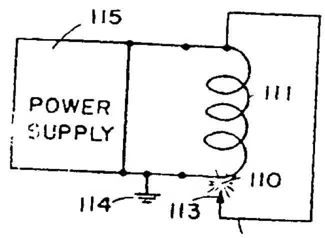

Fig.7

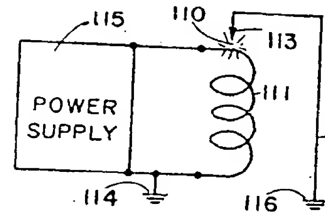

Fig.8

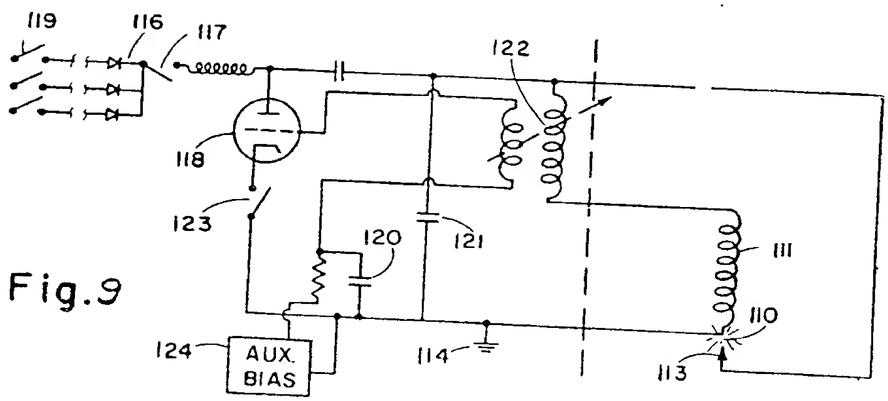

Fig.9

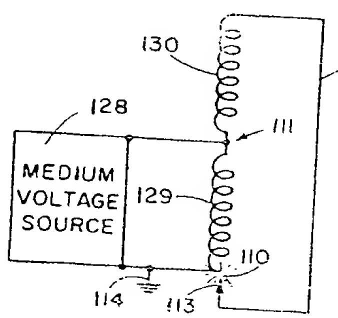

Fig.10

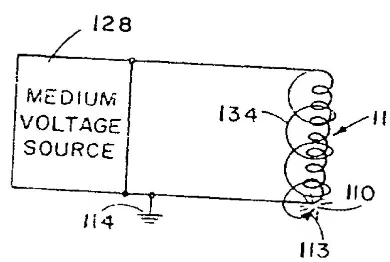

Fig.11

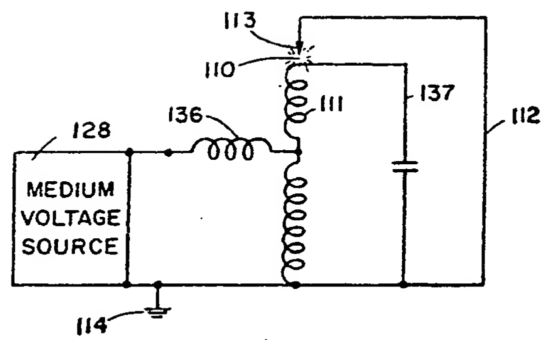

Fig.12

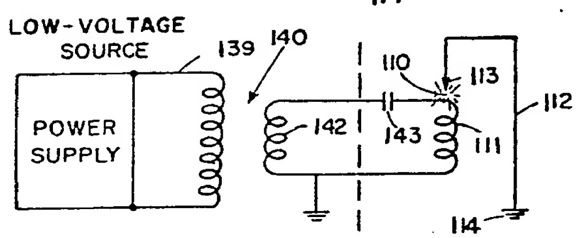

Fig.13

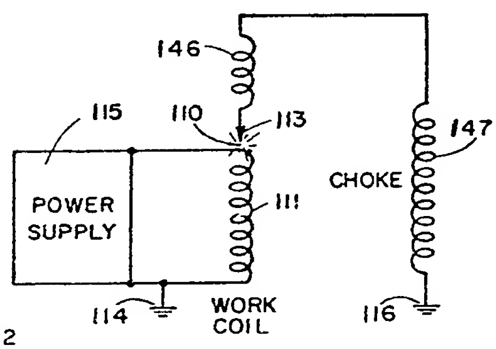

Fig.14

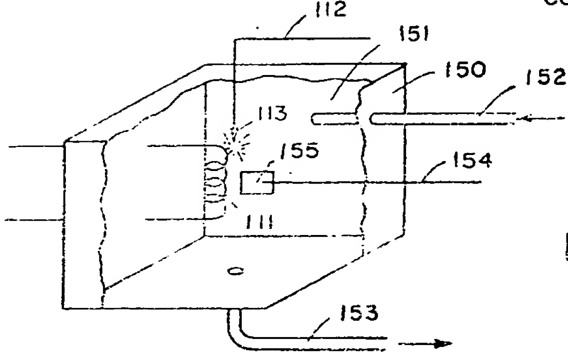

Fig.15

1099693 COMPLETE SPECIFICATION
4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 3 & 4

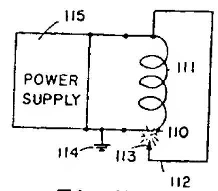

Fig.7

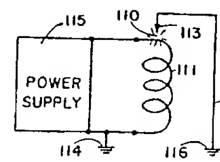

Fig.8

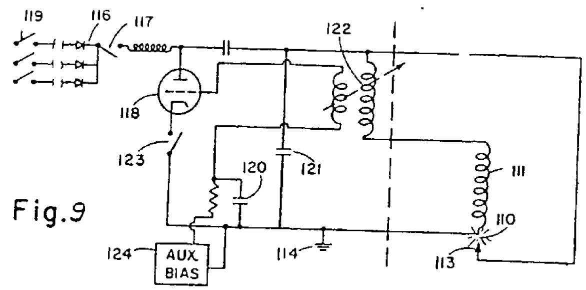

Fig.9

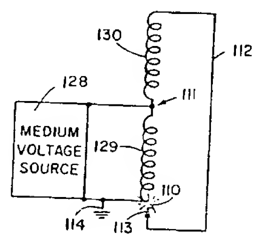

Fig.10

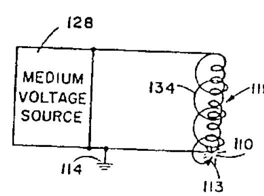

Fig.11

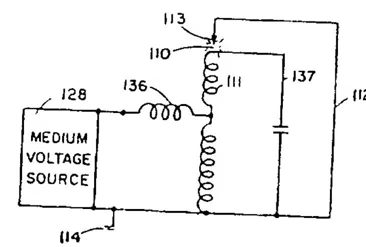

Fig.12

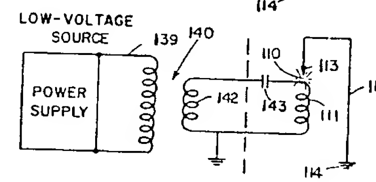

Fig.13

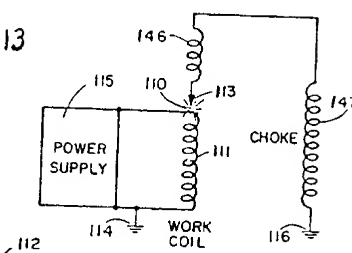

Fig.14

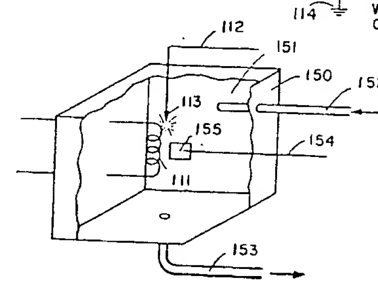

Fig.15